INSTITUTE OF ENGINEERING RESEARCH
BERKELEY, CALIFORNIA

SERIES 3
ISSUE 367

WAVE RESEARCH LABORATORY

PROPAGATION OF RADIAL WAVES GENERATED BY AN OSCILLATING BODY

BY

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JUNE 1954

UNIVERSITY OF CALIFORNIA

University of California
College of Engineering

Submitted under Contract N7onr 295(28)
with the Office of Naval Research

Institute of Engineering Research
Wave Research Laboratory
Technical Report
Series 3, Issue 367

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ABSTRACT

A series of experiments was performed for the purpose of investigating the characteristics of the gravity waves resulting from the periodic vertical oscillation of a plunger in water. Wave heights were measured along a radial line at various distances from the plunger. Graphs are presented which show the relationships between wave height and radial distance, wave height and frequency with constant amplitude of plunger movement, wave height and amplitude of plunger movement with constant frequency.

EXPERIMENTAL EQUIPMENT AND PROCEDURE

Layout:

The experimental investigations were performed in the Fluid Mechanics Laboratory, University of California, Berkeley. The first experiments were performed in a small model basin (see Figure 1); however, this basin was found to be too small. It was possible to measure the wave characteristics only up to a distance of approximately fourteen feet from the center of the disturbance. Because of this limitation, the equipment was moved to a large model basin (65 feet by 120 feet in plan by 2 feet in depth), where most of the experiments were performed.

The experimental layout of the small basin is shown in Figure 1. The basin had a concrete slab bottom and walls. In order to reduce reflection to a minimum, a circular sand beach was installed around the edges of the basin. A portable plunger-type wave generator was mounted at the center of the main basin. Two thin metal wave-splitters were installed on lines radiating from the plunger . Thus a nearly undisturbed segment of the radial waves could travel for a distance of about twenty feet before breaking on the sand beach.

Wave heights were measured at several points (5, 7, 9 and 12 feet from the plunger) in the section between the splitters. The water depth over the horizontal bottom was one foot.

The experimental layout of the large model basin is shown in Figure 2. Radial splitters were not used in this case. The plunger was mounted at one end of the basin near a sloping beach which reduced reflection to a minimum. Instead of building sand beaches around the entire perimeter of this basin to absorb the wave energy, the plunger was operated intermittently and measurements were made before the waves could be reflected from the vertical walls. Observations showed that the reflections started to influence the results approximately thirty-five seconds after the plunger was started. Because of this limitation, measurements were made only during this time interval. The plunger was then stopped and the basin allowed to still before another run was made.

Wave heights were measured at several points (6, 8, 10, 14 and 25 feet from the plunger) along a radial line. Station 10 was used as the reference station. The water depth over the horizontal bottom was kept approximately constant for all runs, and was just over one foot, which resulted in deep water waves in the range of frequencies studied.

Plunger Type Wave Generator:

The plunger used in all of the experiments was of cylindrical shape and was attached to a 110 volt dc motor. The frequency, ω, of the plunger oscillation could be varied by means of two resistors within a range of from 1.5 to about 5 per second. The amplitudes, S, of the plunger oscillation could be varied by changing the eccentricity of the plunger arm; the range was from about zero to a little over six-tenths of a foot.

The plunger was designed so that the shape of the head could be changed; however, a flat head was used in all the runs reported in this paper. A few qualitative tests were performed using a spherical head during which it was observed that more uniform waves were generated.

Measurement of Wave Heights:

Wave heights were measured by means of electrical resistance gages.(5)* Variation in immersion due to passing waves caused the voltage across the gage terminal to vary. The voltage variations were amplified and recorded on a Brush Oscillograph. The resistance gages were calibrated by raising and lowering them in still water by 0.01 foot increments (see Figure 3a). All gages were calibrated at the start and the end of each series. As only a two channel recorder was available it was possible to make measurements at only two locations at the same time (see Figure 3b). Because of this, one gage was used as a reference while the other was connected to the recorder through a selector switch. The output from the reference gage was recorded continuously through each run while the remaining gages were switched in successively.

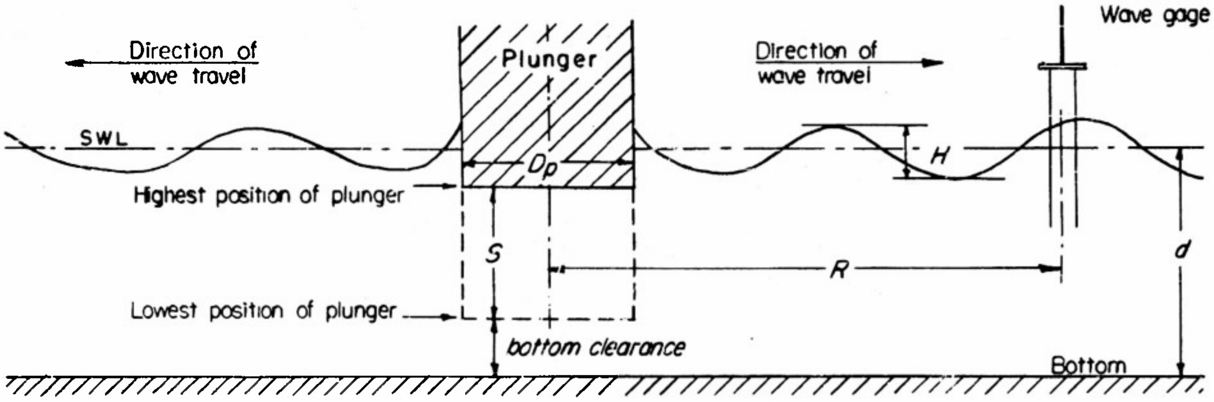
Wave heights at any particular station were obtained by averaging the 10 highest waves of a group of 35 successive waves. When it was not possible to obtain a group of 35 waves from the records, a smaller group was used and a proportionally smaller number of the highest waves were averaged. The wave height at Station 10 served as a scale for the wave heights at other stations (except in the small basin, where the wave height at Station 5 served as the scale). It was discovered, however, that the plunger frequency was not constant throughout a run, but that small fluctuations occurred (up to ±0.015 sec. in periods in some cases), which resulted in variations in wave heights (Table I, Column 10). For purposes of comparison, the percentage variations from the mean of the fluctuating wave heights at Station 10 were computed (Table I, Column 13) and the wave heights at other stations were modified proportionately (Table 1, Column 14). The purpose of this procedure was to minimize the effect of the fluctuation in plunger frequency and possible vibration of the plunger platform.

* Numbers in parentheses refer to references listed at the end of this report.

In selecting the group of waves to be measured, special care was taken to measure the same waves as they advanced past the successive stations.

DEFINITIONS

The terms used in this report were as follows:



D_p = diameter of the plunger, feet.
d = still-water depth, feet.
H = wave height, feet.
R = radial distance from the center of the plunger to the point of measurement, feet.
S = amplitude of plunger motion, feet.
T = wave period, seconds.
ω = frequency of plunger motion, 1/second.
g = acceleration of gravity, ft/sec^2.

RESULTS

The test results are summarized in Table I and in graphical form in Figures 4 to 13.

The Frequency of the Plunger:

For low frequency plunger movement (up to ω = 3.0 per second), traveling waves moved away from the plunger with the frequency of the plunger such that the wave period $T = 1/\omega$. Higher frequencies gave irregular waves, and it was expected [7] that at a certain high frequency of the plunger a change in the waves would occur suddenly. Instead of traveling waves, there would be a standing wave radiating out from the plunger perpendicular to the traveling wave. This was actually observed when the plunger frequency exceeded a certain value; however, no measurements were made because the necessary high frequency could not be used with the given equipment for a long enough period of time to obtain reliable data.

Figures 4,5 and 6 demonstrate the effect of plunger frequency on wave heights. In Figure 4 frequencies of 2.3 and 1.7 were used (with a constant amplitude S), and the wave heights were measured at different distances from the plunger. At each frequency two runs were made maintaining all variables constant. As can be seen, there is little scatter about a mean curve. Some scattering of the points can be seen at Station 6 and also, in some cases, at Station 8. This might be due to the proximity of these stations to the plunger; the waves may not have stabilized. The curves are of simple exponential form from Station 8 to Station 25. The change in form of the curves may be due not only to lack of stabilization close to the plunger, but to bottom reflection.

In Figure 5 ratios of wave height to plunger amplitude are plotted as a function of plunger frequency for the data obtained in the small basin. There appears to be an optimum plunger frequency for which the highest waves are generated. It is probable that this optimum frequency is different for different plunger characteristics (that is, for different values of S and D_p). For the plunger with a diameter (D_p) of 0.50 foot and an amplitude (S) of 0.41 foot, this optimum frequency varied from about 2.8 to 2.9 per second. Further, there seems to be an intermediate frequency where the ratio of wave height to plunger amplitude was at a minimum. As can be seen in Figure 5, this minimum seems to be at about $\omega = 1.9$ to 2.0. In order to investigate this further, additional experiments were made in the large wave basin, using improved equipment which made it possible to obtain higher frequencies. The results are presented in Figure 6.

To allow comparison of the data obtained in both experiments, the data shown in Figure 5 (Station R = 5 feet) were modified by multiplying the heights by the ratio of the two plunger amplitudes, and replotted in Figure 6. As can be seen in Figure 10, this is apparently a legitimate operation. There is considerable scatter of the data, but the trend seems to be definite. The average experimental curve in Figure 6 is very similar to that of Figure 5 with regard to points of maximum and minimum wave heights. The first maximum is approximately the same for both Figures 5 and 6 at the frequency ω of approximately 1.6. The first minimum seems to be also approximately the same for both cases with ω between 1.9 and 2.0. The second maximum at ω between 2.7 and 2.9 is the highest value within the range of experimental conditions. The second minimum is out of the range of Figure 5 and is demonstrated at approximately $\omega = 4$ in Figure 6. The third maximum is not very well defined in Figure 6 because the frequency of the plunger movement was so high as to make the measurements uncertain, and it was necessary to decrease the duration of the run to a minimum to prevent damage to the equipment. At higher frequencies the wave characteristics change entirely and instead of progressive waves, standing waves are formed which radiate in a spoke-like manner from the plunger (orthogonal to the original progressive waves).

No theoretical analysis will be attempted in this report. It is expected, however, that the solution would have a form of a Bessel function* with successive maximum and zero points. The solution depends upon the pressure distribution on the plunger. The latter may be considerably complicated by the bottom reflection in the case of shallow water.

There is apparently no data available to allow prediction of wave characteristics for different size plungers. Observations of other types of wave generators operating at high frequency will perhaps be useful in predicting the operational characteristics of a large cylindrical plunger. Observation of a large scale flapper type wave generator showed the optimum working condition to be at lower frequencies, and the standing orthogonal waves usually started at lower frequencies. For this large wave generator

* Personal communication from R.C. MacCamy

(approximately 60 feet long in water depth of 1.5 feet) the standing orthogonal waves could be observed at a frequency of about 2 (depending on the amplitude of the motion), while on the other hand, for a small plunger-type wave generator used in a 0.5-foot by 4-foot by 20-foot ripple tank where the water depths are usually one inch or less, the phenomenon could be observed only when the frequency exceeded approximately 10.

Figures 7 and 8 show the influence of the plunger frequency, ω , on the decay of the waves as they moved from the center of the disburbance. The data in Figure 7 was obtained in the large basin. The wave height at Station 10 was selected as a reference station, with the wave heights at other stations shown as ratios. As can be seen in Figure 7, the frequency, and hence the wave length, had no noticeable effect on the decay of the waves, at least within the limits of the experimental conditions. At Station 14 there appears to be a downward trend for the shorter wave lengths, but the number of experiments was not sufficient to be certain, and the scatter in data was considerable.

In Figure 8 are plotted the data obtained in the small basin, using the wave height at Station 5 as the reference station. The data show that the shorter waves (higher frequency) have a higher degree of decay. However, one must be very careful in generalizing the data. The effect of radial walls must be considered and, as can be seen later (Figure 12), this appears to be the main reason for the trend. The ends of the radial walls were too close to the center of the disturbance and the opening was too small. It would appear that some of the wave energy was lost at the entrance.

The Amplitude of the Plunger Motion:

Figure 9 and 10 demonstrate the effect of plunger amplitude, S, on wave height. In Figure 9 are plotted data for three different plunger amplitudes (0.615; 0.292 and 0.105 foot). In all cases the plunger (diameter $D_p = 0.50$) was operated at a constant frequency of 2.3. In general the three curves are parallel to each other. The curves fit the equation $H = H_{10}(R_{10}/R)^{\frac{1}{2}}$ fairly well, where H_{10} is the wave height at a radius of ten feet from the plunger.

In Figure 10 wave heights were plotted as a function of the plunger amplitude, S, for each station. The experimental points fall on straight lines, with very little scatter. It can be seen that the wave height, H, is proportional to the amplitude of the plunger.

Wave Height Changes with Distance:

The data obtained in the large wave basin show that the frequency of the plunger motion (hence, the wave length) had little influence on the change of wave heights as they proceed from the center of the disturbance, at least within the range of the experimental conditions. The only variable found to influence the change of wave heights as they travel from the center of the disturbance is the radial distance. The data obtained in the small basin seem, however, to contradict this finding. Figure 8 shows a trend to a faster decrease in wave heights for higher frequencies. The reason for this phenomenon can not be given. It is assumed, however, that this is due to the entrance condition at the wave splitters, as mentioned above and as will again be discussed later.

Figure 11 demonstrates the decrease in wave heights as they travel from the center of the disturbance. In this plot the wave height at Station 10 was taken as the reference station, and the heights at the other stations were shown as ratios. This plot shows the same characteristics as the data presented by Johnson in Figure 3 of Reference 3 for impulsive waves generated by falling weights. In Figure 11 the distances from the center are measured in plunger diameters. The average slope of the curves is approximately 45 degrees.

Figure 12 demonstrates again the change in wave height with respect to the radial distance, R, from the center of the disturbance. The curves were drawn from data obtained in both the small and the large basins and were the result of average values from various runs. In order to compare the data from the small basin and the large basin, the wave height at Station 6 was used as the reference station for both sets.

The mechanics of the height change of radial waves as they expand from the center of the disturbance can be explained in the simplest form as follows:

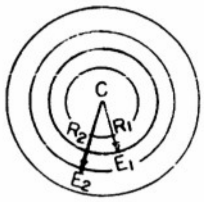
If one assumes that the total energy per wave and the wave length remain constant, then if

E_1 = energy for a unit of wave crest at Point 1
E_2 = energy for a unit of wave crest at Point 2
R_1 = distance from the center of the disturbance to Point 1
R_2 = distance from the center of the disturbance to Point 2

it can be seen that

$$2\pi R_1 E_1 = 2\pi R_2 E_2$$

$$E_1/E_2 = R_2/R_1 .$$



As

$$E_1/E_2 = (H_1/H_2)^2$$

we find that

$$H_1/H_2 = \sqrt{R_2/R_1} .$$

In this consideration, the effects of viscosity and surface tension have been neglected. This assumption is justified when the waves are longer than 0.1 foot, as surface tension becomes relatively small and the rate of damping by internal friction is very small for even short period waves(4).

These theoretical curves have been plotted in Figures 9 and 12. The agreement with the experimental data in the large basin is very good, beginning with the station at 14 feet. The experimental wave heights are somewhat lower than the theoretical curve, as was expected, due to small effects of surface tension and viscosity. There was some disagreement close to the center of the disturbance, but it appeared that no energy was lost, as the experimental curve approaches the theoretical curve as the waves moved away from the disturbed area. The disagreement at the beginning of the curve might be due to the bottom reflection and the eddy disturbances due to plunger movement. Another reason for this disagreement might be the accelerated movement of the waves in the disturbance area caused by the plunger as it splashed water out from the center.

It is probable that for the small basin some wave energy was lost at the entrance between the radial walls. However, the experimentally determined curve starts to run parallel to the theoretical curve in the neighborhood of Stations 10 to 12. It is apparent that radial walls should not be used too close to the disturbance center, nor should they have a narrow opening. The beginning of the radial walls should be clearly beyond the point where irregularities are caused by the original disturbance.

Diameter of the Plunger D_p:

Two plunger diameters used were: D_p = 0.500 foot and D_p = 0.835 foot. In Figure 13 are shown the data for a plunger with D_p = 0.835 foot. (All the previous data were for a plunger with D_p = 0.500 foot.)

The shape of the curve in Figure 13 is similar to the curves for a plunger with a diameter of 0.500 foot (compare with Figures 4, 9 and 12) except for a flat section around Station 10. The same type of flat section can be found in Figure 3 in Reference 3. This flat section might be the result of a larger disturbance and bottom reflection due to the larger plunger diameter and smaller bottom clearance. This is substantiated by the fact that the flat section is moved outward for the higher frequency $\omega = 2.5$ of that for $\omega = 1.4$, as can be seen in Figure 13. The frequency 2.5 gives more disturbance than the frequency 1.4. In Johnson's experiments, this section was almost 30 feet from the disturbance center when heavy weights with large diameter were dropped into shallow water. It is assumed that for greater bottom clearances, and for relatively smaller plunger diameters, the flat section would move inward toward the disturbance center and possibly vanish.

CONCLUSIONS

1. The wave height varies inversely with the square root of the distance from the center of the plunger.

2. There appears to be an optimum frequency of the plunger which generates the highest waves.

3. There appears to be an intermediate frequency where the wave heights are at a minimum.

4. The wave height, H, is proportional to the amplitude of the plunger .

5. The variables of plunger frequency, amplitude, etc., apparently have little influence on the change in height of deep water waves as they proceed from the center of the disturbance (at least in the range of these experiments) so that the law

$$H_1/H_2 = \sqrt{R_2/R_1}$$

is valid for each case.

6. Radial walls, to cut out a segment of wave , should not be placed too close to the center of the disturbance. The opening should not be too narrow.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to J.W. Johnson under whose direction the experiments were completed, and R.L. Wiegel for many helpful suggestions, and for critically reading the manuscript. They are also obligated to M.M. Lincoln for the illustrations and E. Henderson for typing the manuscript.

REFERENCES

1. BEACH EROSION BOARD, Dept. of the Army, A summary of the theory of oscillatory waves, Tech. Report No. 2, Washington, D.C. 1942.

2. HINZE, F. Die Erzeugung von Ringwellen auf einer Flüssigkeitsoberfläche durch periodisch wirkende Druckkräftë - Zeirschrift für angew, Math und Mech., 1936, vol. 16 (3), pp. 143-152.

3. JOHNSON, J.W. and BERMEL, K.F. Impulsive waves in shallow water as generated by falling weights, Trans. AGU, vol. 30, No. 2, pp. 223-230.

4. LAMB, HORACE, Hydrodynamics.

5. MORISON, J.R. Measurements of wave heights by resistance elements, University of Calif., Dept. of Engr. Tech. Report HE-116-270, Berkeley, March 11, 1949.

6. O'BRIEN, M.P. The radially symmetrical movement of wave groups over water of constant depth, University of Calif. Dept. of Engr. HE-116-163, Berkeley, January 1947.

7. SCHULER, F. Erzeugung von Oberflächen durch schwingende Körper - Zeitschrift für angew. Math. und Mech. 1936, Vol. 16 (2); p. 65-72.

8. WIEDENBAUER, H., Das Problem der Ringwellen auf einer Flüssigkeitsoberfläche Zeitschrift für angew, Math. und Mech. 1934, vol. 14-6, pp. 321-332.

9. WIEGEL, R.L. Measurement of surface waves by electrodes, University of Calif. Dept. of Engr. HE-116-269, Berkeley, September 30, 1947.

TABLE I

SUMMARY OF RESULTS

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Run No.	Depth of Water (ft.)	Dia. of Plunger D_p (ft.)	Bottom Clear. of Plunger (ft.)	Ampli. of Plunger (ft.)	Freq. of Plunger $(\frac{1}{sec})$	Period of Waves T (sec)	Station (ft.)	Height of Waves H (ft.)	Corres. Ht. of Waves at 10', H_{10} (ft.)	H/H_{10}	H_{10} ave. for Corres. Run[4] (ft.)	% of each H_{10} of H_{10}ave.	Corrected Wave Ht. for each Sta $H_{corr.}$ (ft.)
8[1]	1.00	0.50	0.505	0.415	2.4-2.5	0.416-0.400	7	0.0260	0.0337	0.77		108.1	0.0240
16	"	"	"	"	"		9	0.0201	0.0272	0.74	H_5 = 0.0311	87.4	0.0230
21	"	"	"	"	"	"	12	0.2150	0.0324	0.66		104.0	0.0207
10	1.00	0.50	0.505	0.415	3.5[2]	0.286	7	0.0158	0.0242	0.65		89.0	0.0178
18	"	"	"	"	"	"	9	0.0186	0.0295	0.63	H_5 = 0.0272	108.5	0.0171
19	"	"	"	"	"	"	12	0.0121	0.0278	0.44		102.0	0.0119
23[3]	1.10	0.50	0.720	0.400	2.35	0.5 - 0.416	6	0.0370	0.0254	1.46		123.0	0.0302
					2.20		8	0.0308	0.0196	1.57		94.7	0.0325
					2.15		14	0.0239	0.0207	1.15	0.0207	100.0	0.0239
					2.23		25	0.0164	0.0189	0.87		91.5	0.0180
					2.10		14	0.0180	0.0189	0.99		87.0	0.0205
24	1.16	0.835	0.440	0.600	2.50	0.400	6	0.0703	0.0577	1.22		103.0	0.0681
					2.5		8	0.0633	0.0613	1.02	0.0558	111.0	0.0576
					2.6		14	0.0519	0.0543	0.96		97.2	0.0543
					2.7		25	0.0291	0.0498	0.58		89.0	0.0327
25	1.16	0.835	0.440	0.600	1.4	0.715	6	0.0609	0.0416	1.46		92.4	0.0451
					1.4		8	0.0455	0.0458	0.99	0.0450	101.7	0.0448
					1.4		14	0.0425	0.0468	0.91		104.0	0.0409
					1.4		25	0.0280	0.0457	0.61		101.4	0.0276
27	1.057	0.500	0.765	0.292	2.38	0.435	6	0.0270	0.0166	1.63		104.2	0.0261
					2.37		8	0.0179	0.0138	1.30		86.7	0.0207
					2.30		14	0.0138	0.0157	0.88	0.0159	98.8	0.0140
					2.36		25	0.0118	0.0175	0.67		110.0	0.0106
28	1.057	0.500	0.765	0.292	2.30	0.435	6	0.0213	0.0154	1.42		93.0	0.0236
					2.3		8	0.0225	0.0174	1.29		104.8	0.0214
					2.3		14	0.0136	0.0166	0.82	0.0166	100.0	0.0136
					2.3		25	0.0125	0.0172	0.73		103.6	0.0121

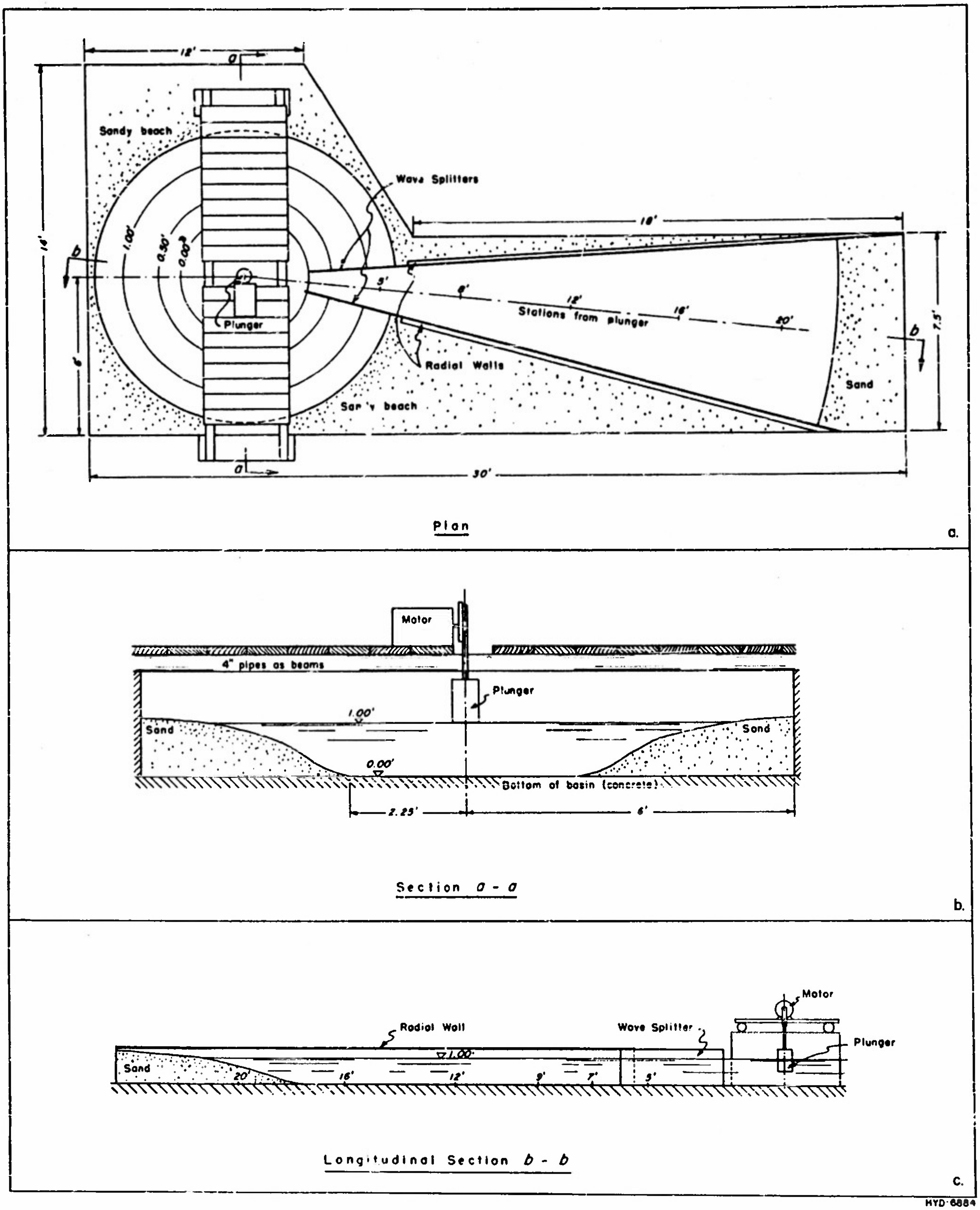
(1) Runs 8-22 were in the small sediment basin
(2) T for 7 and 12 = 0.286, Run 18 for Sta. 9 has probably lower frequency
(3) Data is not very reliable for frequency, ω , varied during the experiment
(4) In small basin, Station at 5 ft. was used as reference station.

TABLE I cont'd

SUMMARY OF RESULTS

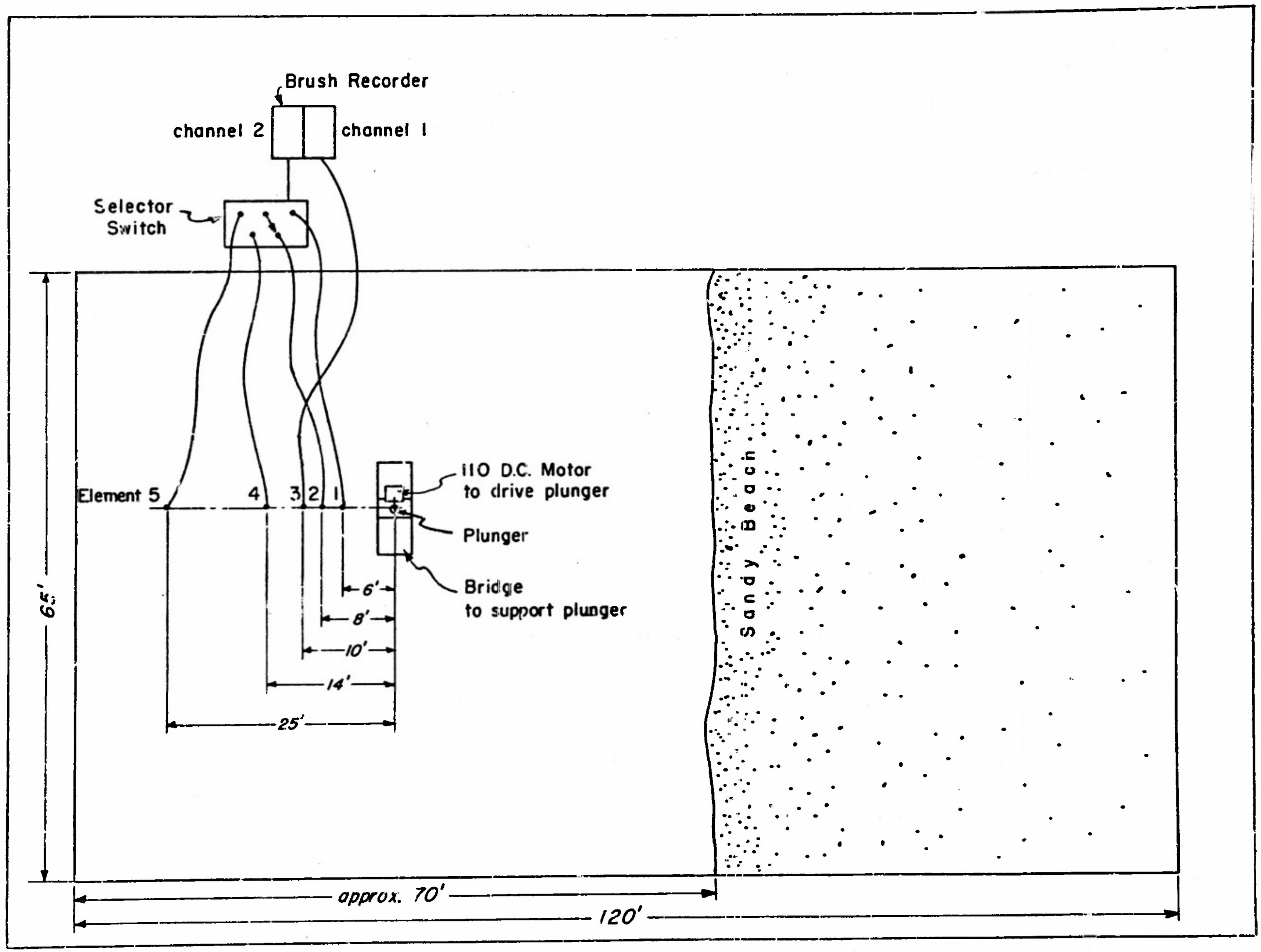
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Run No.	Depth of Water (ft.)	Dia. of Plunger D_p (ft.)	Bottom clear. of Plunger (ft.)	Ampli. of Plunger (ft.)	Freq. of Plunger $\left(\frac{1}{sec.}\right)$	Period of Waves, T (sec)	Sta. (ft.)	Height of Waves H (ft.)	Corres. Ht. of Waves at 10' H_{10} (ft.)	H/H_{10}	H_{10} ave for Corres. Run(4) (ft.)	% of each H_{10} of H_{10}ave	Corrected Wave Ht. for ea. Sta. H corr. (ft.)
29	1.057	0.50	0.595	0.615	1.72	0.589	6	0.0426	0.0329	1.29	0.0303	108.5	0.0391
					1.72		8	0.0366	0.0291	1.26		96.0	0.0382
					1.70		14	0.0269	0.0296	0.91		97.7	0.0276
					1.70		25	0.0202	0.0295	0.68		97.3	0.0206
30	1.057	0.50	0.595	0.615	1.68	0.589	6	0.0400	0.0276	1.45	0.0295	93.5	0.0428
					1.70		8	0.0377	0.0301	1.25		102.0	0.0369
					1.725		14	0.0277	0.0291	0.95		98.6	0.0280
					1.77		25	0.0223	0.0312	0.71		105.0	0.0210
31	1.057	0.50	0.595	0.615	2.26	0.435	6	0.0467	0.0341	1.37	0.0362	94.2	0.0495
					2.28		8	0.0469	0.0382	1.23		105.2	0.0445
					2.30		14	0.0316	0.0372	0.85		102.6	0.0308
					2.20		25	0.0243	0.0355	0.68		98.0	0.0248
32	1.057	0.50	0.595	0.615	2.30	0.435	6	0.0524	0.0354	1.48	0.0379	93.3	0.0561
					2.37		8	0.0460	0.0364	1.26		96.0	0.0479
					2.30		14	0.0320	0.0402	0.80		106.0	0.0302
					2.30		25	0.0198	0.0396	0.50		104.3	0.0190
33	1.057	0.50	0.855	0.105	2.30	0.435	6	0.0106	0.0076	1.39	0.0074	102.5	0.0103
					2.30		8	0.0099	0.0074	1.34		100.0	0.0099
					2.20		14	0.0075	0.0074	1.00		100.0	0.0075
					2.30		25	0.0060	0.0072	0.83		97.2	0.0062
34	1.057	0.50	0.855	0.105	2.34	0.435	6	0.0105	0.0072	1.46	0.0074	97.2	0.0108
					2.30		8	0.0100	0.0078	1.26		105.3	0.0095
					2.30		14	0.0065	0.0069	0.94		93.3	0.0070
					2.30		25	0.0063	0.0079	0.80		106.7	0.0059

(4) In small basin station at 5 ft. was used as reference station.



ARRANGEMENT OF SMALL BASIN

FIGURE 1



SKETCH OF LARGE WAVE BASIN

FIGURE 2

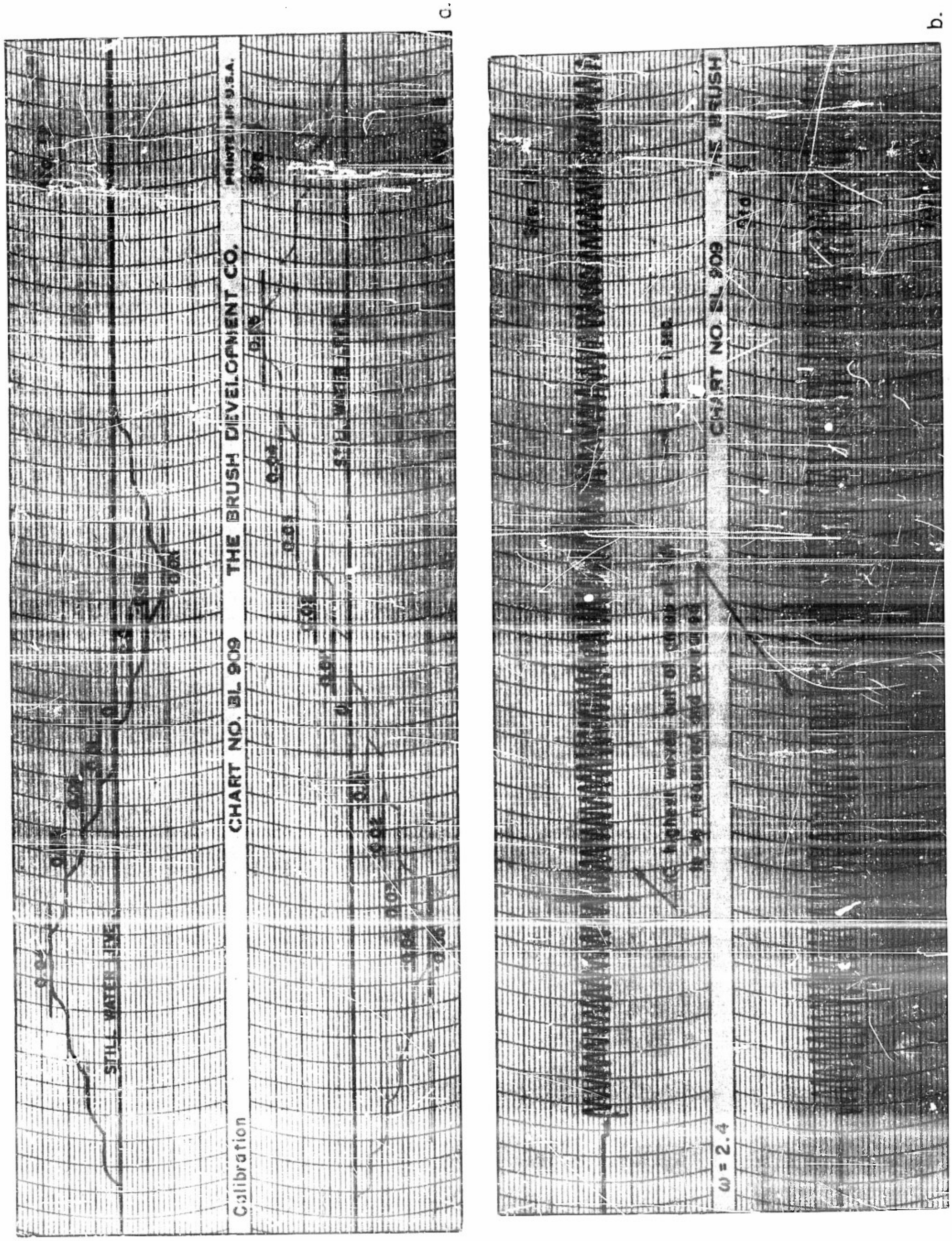
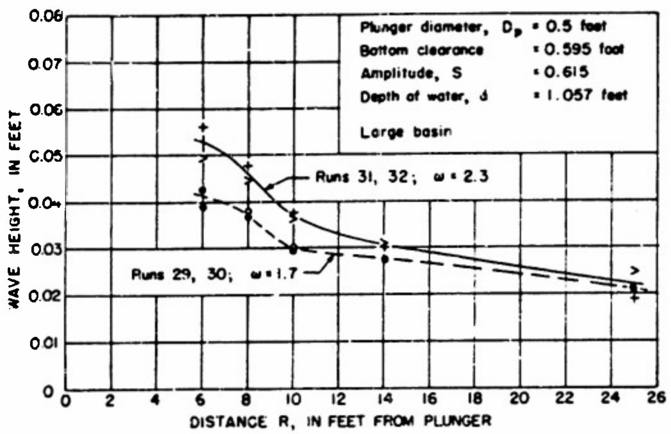
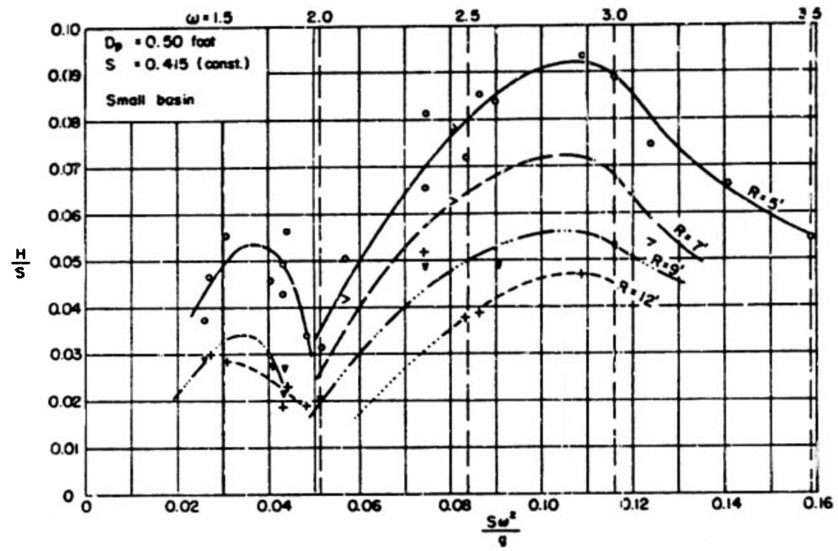

a.
CHART NO. BL 909
THE BRUSH DEVELOPMENT CO.
STILL WATER LINE
Calibration
b.
CHART NO. BL 909
ω = 2.4

FIGURE 3



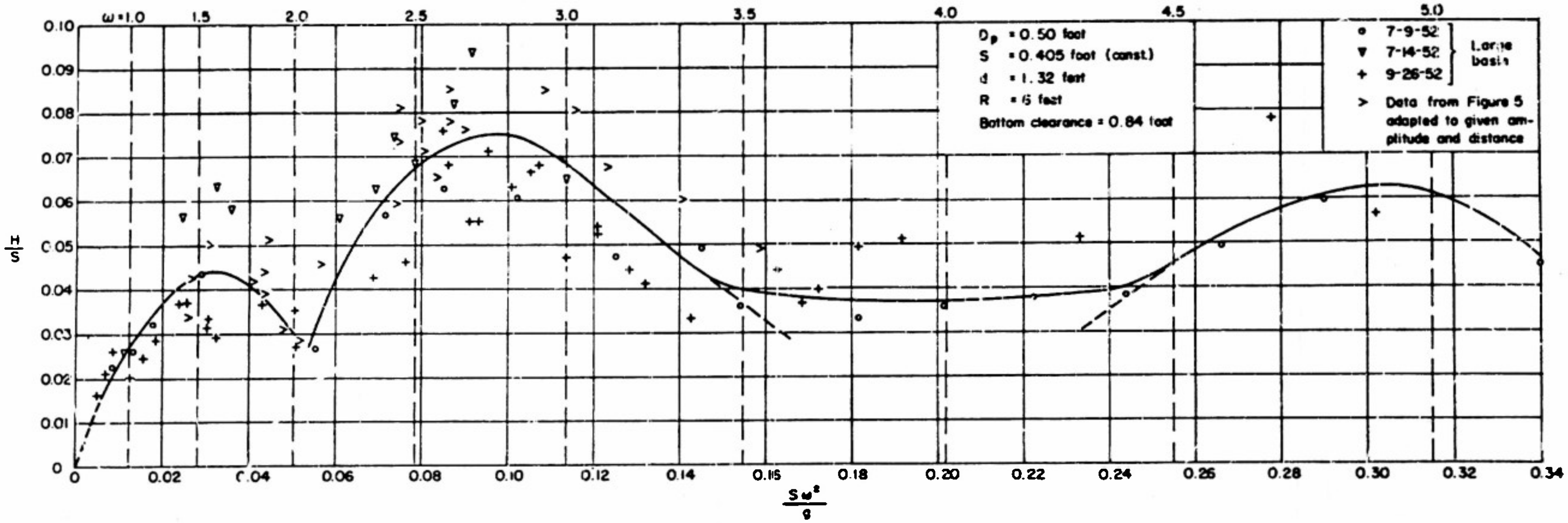
WAVE HEIGHT AS A FUNCTION OF DISTANCE R FROM CENTER OF DISTURBANCE FOR TWO PLUNGER FREQUENCIES

FIG. 4



WAVE HEIGHT AS A FUNCTION OF PLUNGER FREQUENCY ω

FIG. 5

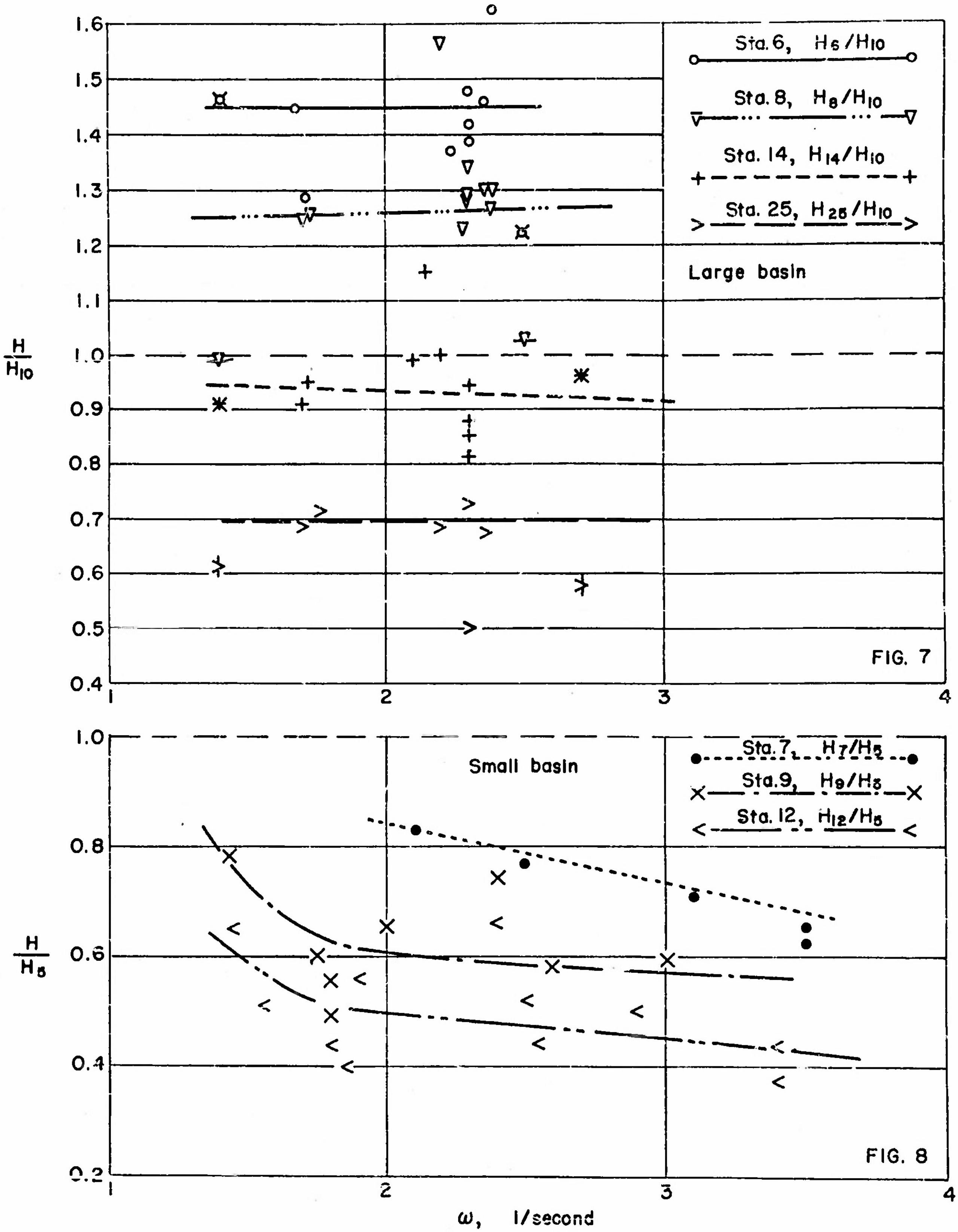


WAVE HEIGHT AS A FUNCTION OF PLUNGER FREQUENCY ω

FIG. 6

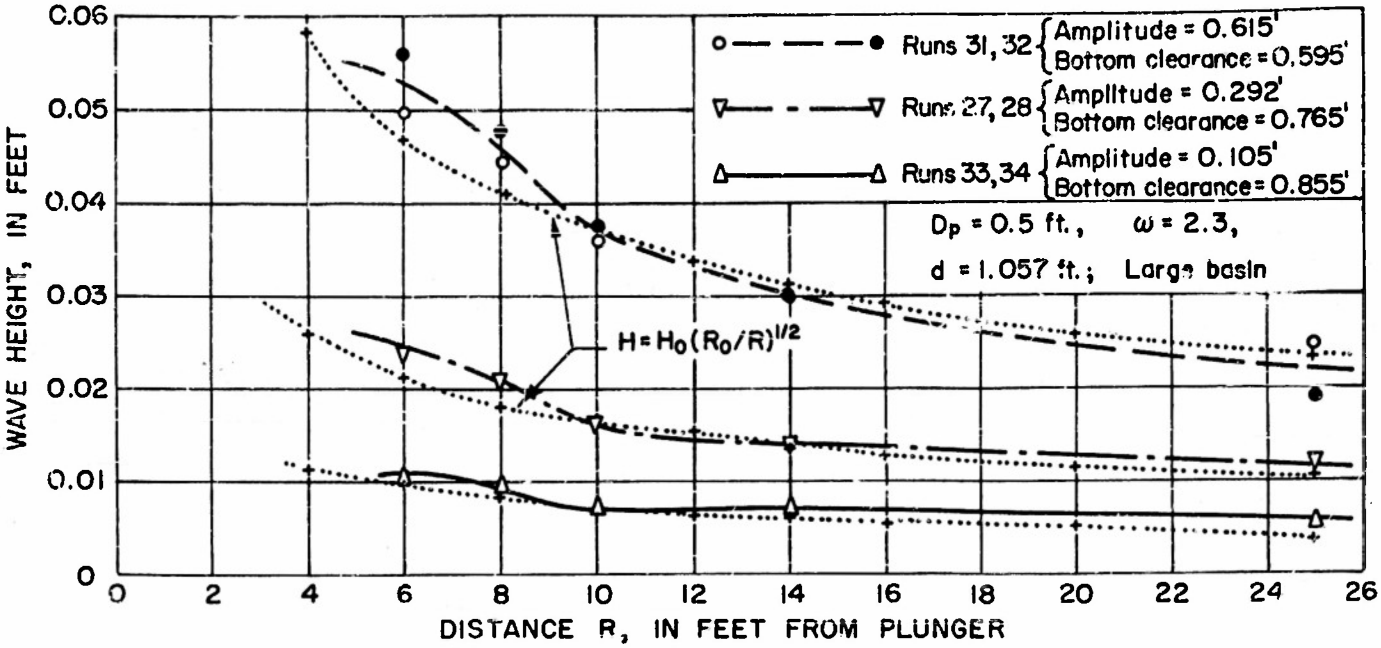
HYD-6886

FIGURES 4-6



DECAY OF WAVES AS A FUNCTION OF PLUNGER FREQUENCY ω

HYD-6887



WAVE HEIGHT AS A FUNCTION OF DISTANCE R FROM THE CENTER OF DISTURBANCE FOR THREE PLUNGER AMPLITUDES

FIGURE 9

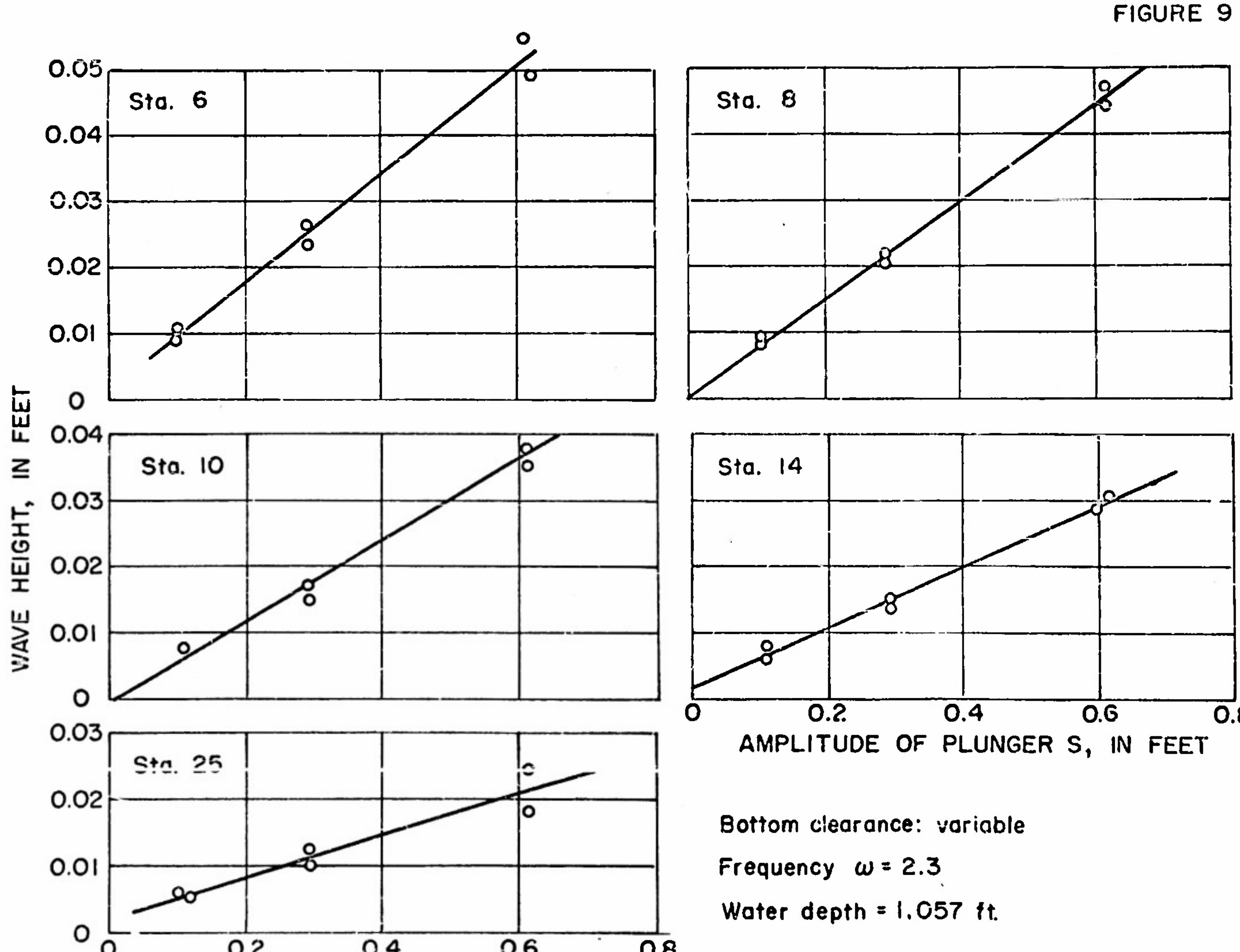
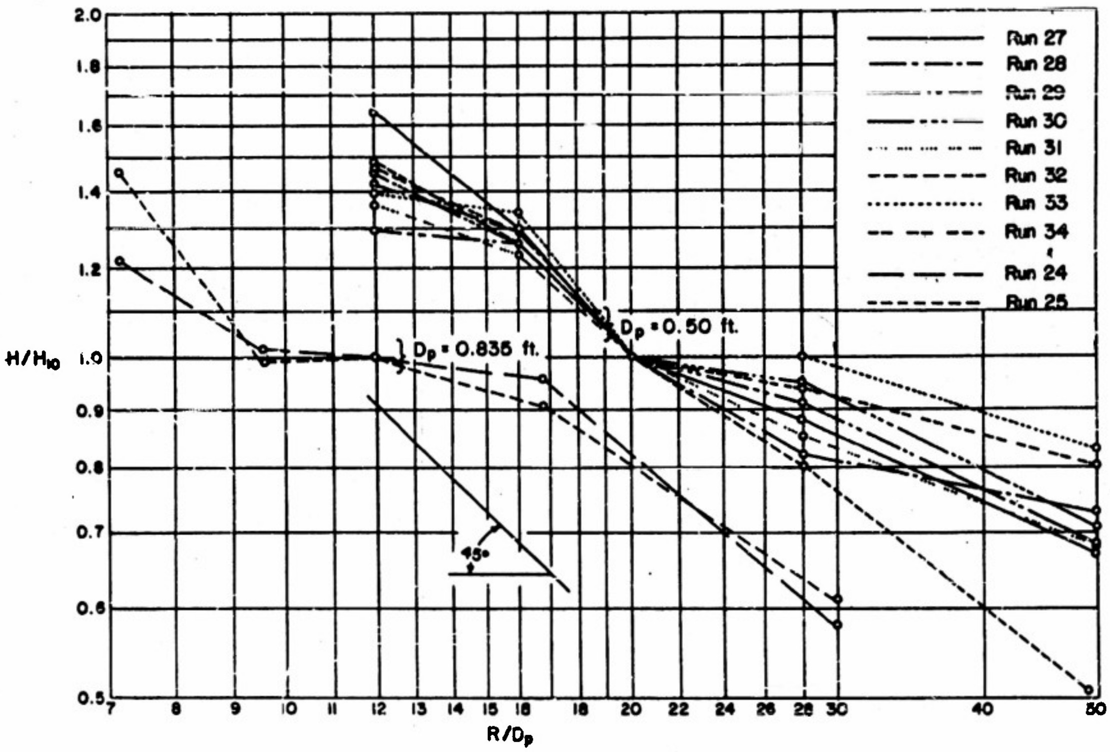


FIG. 10

WAVE HEIGHT AS A FUNCTION OF PLUNGER AMPLITUDE



WAVE HEIGHT AS A FUNCTION OF TRAVEL DISTANCE

FIG. 11

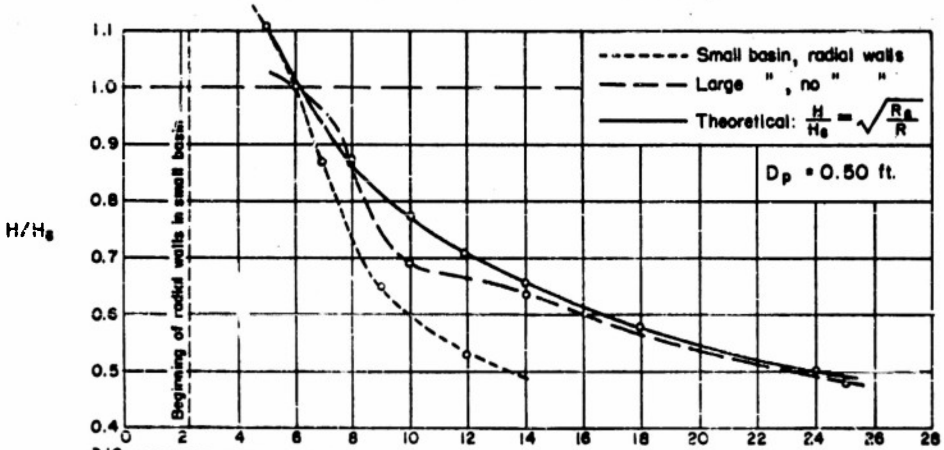


FIG. 12

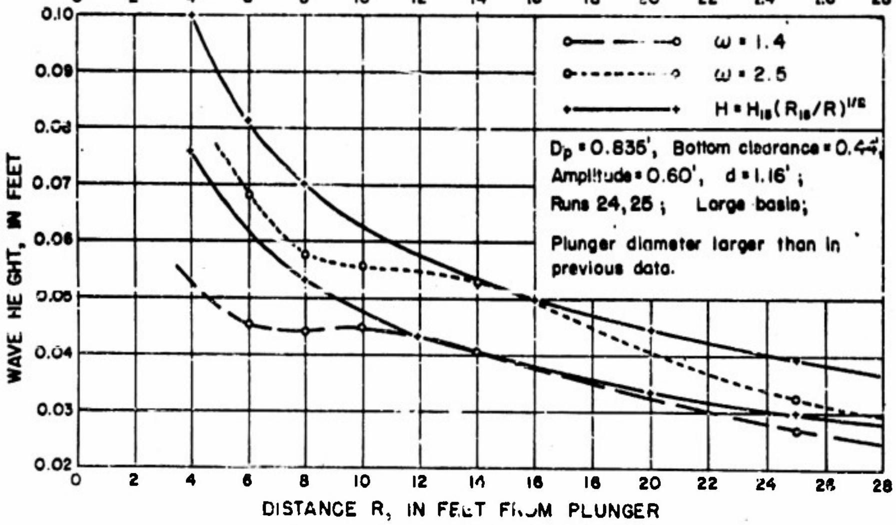


FIG. 13

WAVE HEIGHT (above) AND CHANGE IN WAVE HEIGHT (below) AS FUNCTIONS OF RADIAL DISTANCE R FROM CENTER OF DISTURBANCE

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